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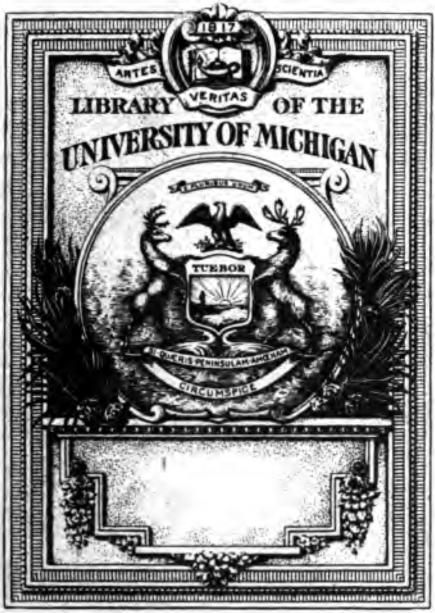

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PROBLEMS
IN THE
USE AND ADJUSTMENT
OF
ENGINEERING INSTRUMENTS.

FORMS FOR FIELD-NOTES.

GENERAL INSTRUCTIONS FOR EXTENDED STUDENTS' SURVEYS.

BY
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PREFACE.

This book is the outgrowth of the difficulties experienced by the author in teaching the first elements of instrumental practice to engineering students. The frequent practice of taking a dozen or twenty students into the field to do a piece of work which can hardly keep more than four or five men busy results generally in the work being really done by the few energetic ones who are anxious to learn, while the rest stand around and pick up what they can—which is frequently an insignificant quantity.

These problems, which have had the benefit of revision after two years' use, are designed to keep each student busy at some definite work, for which he has definite instructions, and to utilize so thoroughly the limited time usually available for this work, that he will have a working knowledge of all the more common engineering instruments by the time he is ready for more advanced work. The student's attention is called to the degree of precision that is required in instrumental work in order to obtain any required precision in the final results—a feature often neglected. Systematic note-keeping, for which forms are given, is required of the students.

This book is not intended to replace any general text-book on Surveying. It aims to supplement the general instructions of such text-books by such definite directions that the students may work *alone,* aided only by such occasional help as may be given by one instructor looking after several parties, and thus solving the vexing problem of properly looking after the work of a large number of students with a limited corps of instruction. The work of many of the problems (e.g., chaining, levelling, angle measurements, etc.) may be so systematized by means of permanent hubs on the surveying ground that the instructor may instantly judge of the character of the work done by a mere inspection of the notes submitted.

As these instructions were written primarily for the use of the students of the University of Pennsylvania, they contain some loc

GENERAL INSTRUCTIONS.

1. Complete notes of each problem, in proper form, tabulated whenever possible, must be made during the progress of the field work.

2. The notes should be so complete that the significance of every recorded number should be easily intelligible to any one conversant with the subject.

3. All calculations must be completed when reports are submitted.

4. Note-books must be turned in each day with the instruments—except when the problem requires extended computations on the data obtained in the field, in which case two days' extra time will be allowed.

5. The note-book should be a journal of each day's field-work—giving (*a*) date, (*b*) time of beginning and ending work, (*c*) number of problem, (*d*) *personnel* of party, and then a detailed report of individual work.

6. No notes are to be copied from another's note-book, except such figures as target readings of a level rod, etc., taken by the assistant, which will be necessary for a complete report on the problem. With such exceptions each student reports *only* his own individual work.

7. When a problem requires the work of two or more (as is usually the case) *each* student in turn must act as chief, do the instrumental work, and take notes for a *complete* solution of the problem.

8. Even when a student acts only as assistant during any one day's work, a report must be submitted by him giving date, time of work, number of problem, and *personnel* of party.

9. No credit will be given for field-work except as it can be estimated from the notes. No verbal reports will be credited.

10. Read the instructions carefully *before* beginning the field-work on any problem; be sure that all necessary equipment is provided and that the instructions are understood.

11. Students are held responsible for all equipment issued to them. Therefore, examine all equipment as it is issued and report *immediately* any injury or deficiency that may be discovered, in order that *the responsibility* may be properly located.

PROBLEMS IN THE USE AND ADJUSTMENT

OF

ENGINEERING INSTRUMENTS.

— 1 —

LINEAR MEASUREMENTS—LINK-CHAIN.

Equipment: Link-chain, set of marking-pins, two transit-poles, two iron plumb-bobs.

Set a transit-pole at each of two designated hubs about 600 feet apart. Measure the distance *three* times, lining in by eye, taking precautions to have the two ends of the chain always at the same level, "breaking chain" if necessary, etc.

Always drag the chain ahead its full length, even if it is necessary for the head chainman to walk back to "break chain." Always place a pin at each even hundred feet, and begin again at that point for a new chain length.

Each student makes a *set* of three measurements acting as head chainman. The extreme range of the three values should not be more than $\frac{1}{1000}$ of the distance.

NOTES.—For this simple problem a mere description, giving the locality of the work, the three measurements obtained, and other information called for in the general directions, is all that is necessary.

— 2 —

LINEAR MEASUREMENTS—STEEL TAPE.

Equipment: 100-foot steel tape, two transit-poles, two brass plumb bobs, foot-rule, hatchet, and twelve stakes.

Set a transit-pole at each of two designated hubs about 600 feet apart. Drive stakes on line, at least one every 100 feet, and also one at every point where it is necessary to "break chain," placing them so that an even-foot mark will come on top of the stake. Measure the distance *three* times. Transfer the measurements to the tops of the stakes very carefully, using a plumb-bob if necessary, and mark the point with a pencil. Measure the final fraction of a foot with the foot-rule. The extreme range of the three values should not be more than $\frac{1}{2500}$ of the distance. Each student makes a set of *three* measurements, acting as head chainman. The intermediate stakes should be pulled and re-driven between each set, so as to make the measurements absolutely independent. The stakes may be aligned by eye, aided by the plumb-bobs.

NOTES. [See NOTES for Prob. 1.]

— 3 —

LINEAR MEASUREMENTS—TESTING CHAIN (OR TAPE).

Equipment: Chain (or tape) to be tested, standard tape, spring-balance, two brass plumb-bobs, triangular scale, and a small strip of cardboard (e.g., visiting-card).

1. Unroll the standard tape in a suitable place.* Set one of the end marks at some well-defined mark on the floor (e.g., a scratch in the top of a nail head) and tack the strip of cardboard under the other end mark of the tape. Pull the tape to a tension of 16 lbs., and mark on the cardboard with a *sharp hard* pencil the position of the 100-foot mark. Make a similar measurement with the chain or tape to be tested, and measure the difference if any.

2. Observe by several trials the changes in the length of the chain (or tape) by making the tension 12 lbs. and then 20 lbs. Compute the average change for one pound variation in pull.

3. Hold the chain (or tape) to be tested clear of the floor and note what tension is necessary to bring the end marks at the same distance apart as when supported throughout its length with a tension of 16 lbs. Use brass plumb-bobs in this test to bring the end marks over the points on the floor.

NOTES. [See NOTES for Prob. 1.]

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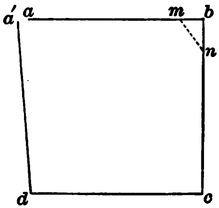
* A passageway or hall is often the only available place, and serves very well except for interference to and by others. A smooth level sidewalk will answer the purpose in fair weather. The vacant space under the seats of a large grand stand may sometimes be utilized as a permanent place for these as well as other long-tape tests.

— 4 —

CHAIN-SURVEYING—LAYING OUT RIGHT ANGLES.

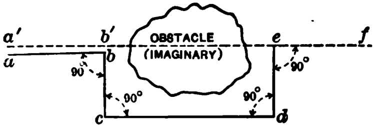
Equipment: Link chain, set of marking-pins.

1. Select an area where a square about 250 feet on a side can be laid out. Select *a* and *b* *about* 250 feet apart. Lay out a right angle at *b*, using the "3, 4, 5 method." Measure *mb*=30 feet. Fix the zero of the chain at *b* (fastening it with a marking-pin) and have one man hold the 90-foot mark at *m*. Swing the 40-foot mark until both sections of the tape are taut and the angle *mbn* will then be a right angle.



Measure off *bc*=*ab*. Lay out a right angle at *c* and make *cd*=*ab*. Lay out a right angle at *d* and make *da'*=*ab*. Measure *aa'* and compute the "error of closure" (which equals *aa'* divided by the total perimeter).

2. To chain a line through an obstacle (imaginary in this case). Select two points *a* and *b* as in figure. Lay off right angles at *b*, *c*, *d*, and *e*, making *bc*=*de*. Produce *ef* backward and note value (if anything) of *bb'* and *aa'*. Measure *eb*.



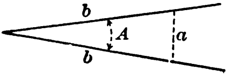
NOTES.—Sketches as above with statements of the required results will constitute a sufficient report. The magnitude of the errors will indicate how much reliance can be placed on such methods.

— 5 —

CHAIN-SURVEYING—OBLIQUE ANGLES.

Equipment: Chain, two transit-poles, set of marking-pins.

Set five marking-pins as witnesses near five designated hubs, which should be about 300 feet apart, and form an irregular pentagon.



1. Measure all the angles by the method suggested in the figure, using the formula $\sin \frac{1}{2}A = \frac{a}{2b}$.

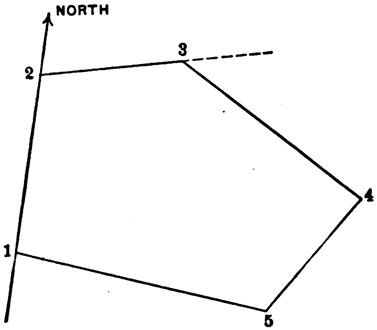
If the angle is much greater than 90°, it may be more convenient to produce one of the sides and measure the supplement of the angle (e.g., angle 3 in the figure). Note whether the sum of all the interior angles is nearly 540°.

FORM OF NOTES.

Angle	b	a	$\frac{a}{2b}$	$\frac{1}{2}A$	A
1	40	58.7	.734	47° 13′	94° 26′
2	40	62.8	.735	51° 43′	103° 26′
3	40	29.5	369	21° 40′	(sup.) 136° 40′
4	40	55.2	.690	43° 38′	87° 16′
5	40	68.5	.856	58° 52′	117° 44′
					539° 32′

Course.	Bearing. (merid. assumed.)	Distance.	Latitude.	Departure.
1....2	N	252.8	+252.8	——
2....3	N 76° 34′ E	204.6	+ 47.5	+199.0
3....4	S 60° 06′ E	320.7	− 159.9	+278.0
4... 5	S 32° 38′ W	207.2	− 174.5	− 111.7
5 ...1	N 85° 06′ W	363.8	+ 31.1	− 362.5
		1349.1	+331.4 − 334.4	+477 0 − 474.2
			3.0	2.8

2. Measure the sides. Assume one side as meridian, and from the measured angles compute the corresponding bearings of the other sides. For example, the bearing of 3 . . . 4 is S 60° 06′ E; i.e., the bearing of 4 . . . 3 is N 60° 06′ W. The angle at 4 is 87° 16′, which means that 4 . . . 5 runs in a direction 147° 22′ (the sum) from North or 32° 38′ from South. Therefore the bearing of 4 . . . 5 is S 32° 38′ W. Compute the latitudes and departures and then the error of closure. The *latitude* equals the distance times the *cosine* of the bearing; the *departure* equals the distance times the *sine* of the bearing. The *error of closure* is the quotient (generally expressed as a fraction whose numerator is one) of the square root of the sum of the squares of the errors of the latitudes and of the departures divided by the total perimeter.



$$\text{Error of closure} = \frac{\sqrt{3.0^2 + 2.8^2}}{1349.1}$$
$$= \frac{1}{329}$$

— 6 —

COMPASS PRACTICE—SIGHTING AND READING NEEDLE.

Equipment: Surveyor's compass.

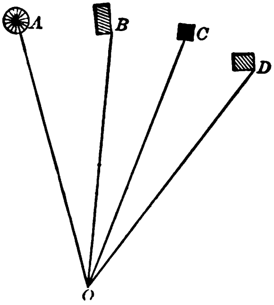
Set up the compass over some fixed hub designated by the instructor in charge and point at four well-defined points (e.g., church steeples, corners of buildings, etc.), which will be also designated. After sighting at all four points in turn and taking the needle reading on each to the nearest 5′ of arc, move the declination arc slightly and again take the needle readings on all four points. Take four such sets of readings. Calling *O* the position of the instrument and *A*, *B*, *C*, and *D* the points sighted at, four values of the angle *AOB* may be obtained by taking the differences of the bearings. Similarly four values of each of the other angles may be obtained. The discrepancies will give some idea of the reliability of needle readings.

FORM OF NOTES.

	1st Reading.	2d Reading.	3d Reading.	4th Reading.	Mean.
Point *A*	N 13° 20′ W	N 15° 10′ W	N 16° 25′ W	N 17° 10′ W	
" *B*	N 1° 35′ E	N 0° 20′ W	N 1° 30′ W	N 2° 15′ W	
" *C*	N 64° 30′ E	N 62° 35′ E	N 61° 15′ E	N 60° 45′ E	
" *D*	N 77° 45′ E	N 76° 0′ E	N 74° 55′ E	N 74° 15′ E	
Angle *AOB*	14° 55′	14° 50′	14° 55′	14° 55′	14° 54′
" *BOC*	62° 55′	62° 55′	62° 45	63° 00′	62° 54′
" *COD*	13° 15′	13° 25′	13° 40′	13° 30′	13° 27′

Abnormal discrepancies in the angles may sometimes occur on account of the attraction caused by a knife, keys, or a steel key-chain in the pockets of the observer, or by a steel band in the brim of the observer's hat. A wagon, temporarily halted near the instrument, especially if loaded with iron, will probably cause an appreciable disturbance of the needle. The student will find it a useful exercise, in connection with this problem, to determine the effect, by careful and repeated trials, of purposely allowing such sources of attraction to be held first on one side and then on the other side of the instrument. To be of any value, this test should only be made in a way that might occur *naturally* while using the instrument.

Tower Blind Asylum.
S W. cor. 34th and Market Sts.
Tower of The Bartram.
N. W. cor. Chem. Lab.



— 7 —

COMPASS PRACTICE—ERRORS OF SIGHTING; SETTING BY NEEDLE AND LINING IN.

Equipment: Compass, transit-pole, foot-rule, board about 2 feet long and 6 or 8 inches wide.

1. **Error of sighting.** Set up the compass where a clear view of 600 feet may be had. Have the rodman pace off 200 feet and lay the board on the ground with its length transverse to the line of sight, taking care to fix the board very firmly. If a bit of smooth clean pavement is at hand, it will be preferable to the board, being rigid. Sight at the rod held at some marked point near the centre of the board. Clamp the vertical axis. Have the rodman measure the distance of this point from one end of the board and then move the

Form of Notes.

Distance.	Distance of rod from end of board.	Error. (d)	d^2		
	"	"			
200	12.0	.18	.0324		
	12.8	.62	.3844		
	12.6	.42	.1764		
	10.8	1.38	1.9044		
	etc.	etc.	etc.		
	....	...	...		
	....	....	....		
Sum =	121.8		5.2680		
Mean =	12.18				
600	(simi	larly)			
200	(simi	larly)			
600	(simi	larly)			

rod away. Line in the rod again, and again have the rodman measure its position. Repeat at least 10 times. Compute the "probable error" (see pp. (46, 47) of a single sighting in *linear* distance. Reduce this error to its angular value by dividing the error by the distance from the instrument. The quotient is the tangent of the angular error.

Repeat this test at a distance of 600 feet.

2. Error of setting by needle and lining in. Read the needle to the nearest 5′ when pointing at some one point on the board. Turn the compass a little on its vertical axis and have the rodman move the rod away. Set the compass at the *same needle reading,* and again line in the rod. Have the rodman note the position of the rod as in the first part of the problem. Repeat 10 times at both 200 and 600 feet distance.

CAUTION.—Be sure that the *declination arc* is not disturbed during the progress of the work.

$$E_1 = .6745\sqrt{\frac{5.268}{(10-1)}} = 0''.52 = 0'.043$$

$$\frac{0.043}{200} = .000215 = \tan 0^\circ\ 0'\ 44''$$

Constant compass reading—N 62° 25′ E

Constant compass reading—N 67° 50′ E

COMPASS PRACTICE—RUNNING OUT A LINE HAVING A CONSTANT BEARING.

Equipment: Compass, transit-pole, set of marking-pins.

Run out a line about ½ mile long, on uneven ground, setting pins at each station, using a *constant* bearing. Pace the distances between stations. Then run back by the reverse bearings and have the rodman note the discrepancy at each station. After noting the error the rodman transfers the marking pin to the new position, which will make the entire return line continuous and independent. Be careful to select stations where there will be no *local attraction* (e g., from lamp-posts, iron fences, etc.). Where local attraction is suspected, take a back-sight and determine its amount. The work will demonstrate the compensating character of the errors, the degree of accuracy that may be expected, and the frequency even in suburban localities of greater or less local attraction.

FORM OF NOTES.

Sta.	Bearing.	Distance.	Errors on return.	
0	S 65½° W	350	S 0.4	
1	S 65½° W	420	N 0.6	
2	S 60¼° W	370	N 1.8	Local attr. suspected at sta. 2. B. S. to sta 1, N 60¼ E.
3	S 65½° W	640	N 0.4	B. S. to sta. 2, N 65½ E.
4	S 65½° W	260	S 1.0	
5	S 65½° W	480	S 0.3	
6	——	370	——	Bearing on return line from sta. 6, N 65½ E.

— 9 —

LEVEL PRACTICE—READING ROD AND SETTING TARGET.

Equipment: Wye-level, "Philadelphia" level-rod.

1. Send the rodman about 200 feet away on a nearly level stretch. Sight on the rod held on a peg or on a smooth solid knob of stone or brick and direct the setting of the target, which is then read to the nearest .001 foot and recorded by the rodman. The rodman then moves the target a few inches up or down and the target is again set and read. Obtain 10 such values. Find the "probable error" (see pp. (46, 47) of the mean and of a single observation.

2. Turn the rod so that the leveller sees the numbers on the *back* of the rod. The leveller reads the rod directly to the nearest .01 foot and records the reading. The rodman then extends the rod *about* 0.1 foot, reading and recording the exact movement to the nearest .01 foot as shown by the index. The leveller again reads and records the rod reading. This is done 10 times. Subtract the total rod movement as reported afterward by the rodman from the rod reading to which each corresponds. The results should be nearly identical. Compute the "probable error" as in Part 1. This exercise tests the ability to read a "speaking rod."

3. Repeat Part 1 at a distance of about 600 feet. This will test the ability to read a target at a distance.

FORM OF NOTES.

No. of observ.	Rod reading.	d	d^2	Dist.		
1	5.203	.001	.000 001	200		
2	5.206	.002	004			
3	5.199	.005	025			
etc.	etc.	etc.	etc.			
...	....	.	....			
10	5.201	.003	.000 009			$E_1 = .6745 \sqrt{\frac{.000\,156}{10 - 1}} = .0028$
Sum Mean	52.041 5.204		.000 156			$E_m = \frac{.0028}{\sqrt{10}} = .00088$
(simi	larly)			600		
No. of observ.	Rod reading.	Rod extension.	Diff.	d	d^2	
1	8.63	—	8.63	.02	.0004	Distance about 200 feet.
2	8.71	.08	8.62	.03	9	
3	8.81	.19	8.62	.03	9	
4	8.96	.32	8.66	.01	.0001	
etc.	etc.	etc.	etc.	etc.	etc.	

— 10 —

LEVEL PRACTICE—DIFFERENTIAL LEVELLING.

Equipment: Wye-level, level-rod.

Run a line of levels over a series of designated hubs. Assume some designated bench-mark to have an elevation of 100 feet above the datum-plane. Record all rod readings when held on turning-points for fore-sights in the column headed F. S. Rod readings on points not used as turning-points are recorded as "intermediate sights" (I. S.). The line of levels is to form a complete circuit ending on the hub at which the line started—as a check. Do not use the target on the level-rod. The leveller reads the rod directly, estimating to 100ths of a foot. If a height of over 7 feet is required, the rod is elongated to its full length. (This assumes the use of the "Philadelphia" self-reading rod.) With some rods the target must be used. To guard against error, the target is sometimes used on all turning points (T. P.), the readings taken and recorded independently by *both* rodman and leveller.

FORM OF NOTES.

Sta.	B. S.	H. I.	F. S.	I. S.	Elev.	
B. M.	3.64	103.64			100.00	B. M. on curb at S. E. cor. 34th and Spruce Sts.
T. P.			7.48		96.16	
	4 29	100.45				
Hub_{25}				7.19	93.26	
T. P.			7.06		93.39	
etc.						

—11—

LEVEL PRACTICE—PROFILE LEVELLING.

Equipment: Wye-level, level-rod, 50-foot tape. The student must be provided with a small sheet of profile-paper, Plate A.

* Obtain first the standard length of the street-car rails on Woodland Ave. Measure any odd lengths that may be found, and the lengths of frogs, etc , at switches and crossings. Beginning at the first rail-joint on the south side of the south track on Woodland Ave., just west of the switch running on to Walnut St., obtain the elevation of each rail joint of that line of rails up to the first frog at the intersection of Woodland Ave. and Spruce St.

Assume the datum-plane as 100 feet below the curb at the S.W. corner of 34th and Walnut Sts. Note the elevation of the curb at the east intersection of Woodland Ave. and Spruce St.

Draw the profile on profile-paper (Plate A), horizontal scale 100 feet to the inch, vertical scale 10 feet to the inch.

NOTES.—Similar to those for Prob. 10. Rod readings for rail-joints should be put in column "I. S." except when used as turning-points. The "stations" in the first column should be in each case the continued sum of all the rail-lengths up to that point, e.g., 0, 0+30, 0+60, 0+90, 1+20, etc. As a check on the numerical work, note whether the sum of the back-sights (B. S.) minus the sum of the fore-sights (F. S.) equals the elevation of the first bench-mark minus the elevation of the final bench-mark.

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* It was considered that these directions could be made most valuable by applying them to a definite locality rather than to make them purely general. The necessary modifications to apply them to any locality can be readily made. These remarks apply equally to several other problems.

—12—

LEVEL PRACTICE—TESTING ADJUSTMENTS.

Equipment: Wye-level, level-rod, 100-foot tape, set of marking-pins.

The object of this problem is to make the student as familiar as possible with the adjustments, without subjecting the instrument to the injury that would result from excessive disturbance of the adjusting-screws, especially in unskilful hands. Therefore no adjusting-screws are to be disturbed, but the value of each error of adjustment is determined, assuming all previous adjustments as already made. Making three trials of each adjustment will demonstrate to the student that unless *extreme care* is taken in handling the instrument, the three trials will not exactly agree, and that he will sometimes find an apparent small error when the adjustment is practically perfect. This note applies equally to Problem 16.

1. To make the line of sight parallel to the axis of the bubble.

FORM OF NOTES.

	1st Trial.	2d Trial.	3d Trial.	Mean.	
1st Adj. (*a*)					
Tel. dir.	3.684	3.986	3.902		
Tel. inv.	3.692	3.995	3.909		
½ diff.	.004	.0045	.0035	.004	
1*b*	0.6 div.	0.8 div.	0.7 div.	0.7 div.	
2					
3	0.8 div.	1.1 div.	0.9 div.	0.9 div.	
Ang. val.	of one div. of	bubble			
E	15.8 3.6 12.2	15.4 5.6 9.8	14.8 4.2 10.6		
O	15.2 2.8 12.4	13.2 3.1 10.1	13.1 2.2 10.9		
R	4.931 4.211 .720	4.867 4.294 .573	4.831 4.208 .623		
a″	30″.2	29″.7	29″.9	29″.93	

a. Measure off a base 400 feet long on nearly level ground and set up the level at one end of the line. Sight at the rod at the other end. Have the vertical axis clamped, and the whole instrument as rigid as possible except the clips over the telescope, which should be loose so that the telescope can be rotated in the wyes without shaking the instrument. If the line of collimation is in adjustment the rod reading will be the same, when the telescope is rotated half-way, as at first. The difference, if any, is *twice* the error. ***Make three tests.*** Raise or lower the telescope between each test so as to bring the readings on a different part of the rod.

b. Bring the telescope directly over a pair of levelling-screws and clamp the vertical axis. Bring the bubble to the centre with the levelling-screws. Reverse the telescope in the wyes. If the bubble again comes to the centre, the wyes are level and the line of collimation is parallel to the axis of the bubble. If the bubble does not come to the centre, move the levelling-screws until the bubble is moved *half-way* back. Reverse the telescope again, and the bubble will come very nearly if not quite to its position before reversal. Keep adjusting the levelling-screws until the bubble remains in one

dist. = 400 ft.

Bubble moves forward about one division when swung to the right about 30°; moves backward when swung to the left.

dist. = 400 ft.

place in the tube for the telescope in either position. Under those conditions the wyes are level and distance of the centre of the bubble from the centre of the tube is the error of adjustment. Record this distance measured in divisions of the bubble-tube. *Make three tests.*

2. To bring the bubble axis into the vertical plane through the axis of the telescope. Bring the bubble to the centre of the tube, first observing that the bubble-tube hangs directly under the telescope. Rotate the telescope slightly in the wyes, and note whether the bubble remains in the centre, or if it moves in one direction for a swing to the right and in the other direction for a swing to the left.

3. To make the axis of the wyes perpendicular to the vertical axis of the instrument. Bring the bubble to the centre over both pairs of levelling-screws and then rotate the instrument about its vertical axis 180°. Correct one half the error, if any, with the levelling screws; make the same correction for the other levelling screws. The bubble will then remain nearly, if not quite, in the same place for any position of the telescope. Keep adjusting until this is true. The distance of the centre of the bubble from the centre of the tube is a measure of the correction that should be made by the adjusting-screw under one of the wyes. Record the error, if any, in divisions of the bubble-tube. *Make three tests* by purposely throwing the instrument out of level after each test and making an independent determination.

Value in seconds of arc of one division of the level-tube. Run the bubble to near one end of the tube, but still keeping both ends of the bubble within the graduated divisions on the tube. Take a reading on the rod held 400 feet away. Move the bubble to the other end of the tube and again read the rod.

Let E = the movement, in divisions, of the eye end of the bubble;

Let O = the movement, in divisions, of the object end of the bubble;

Let R = difference in rod readings;

$$\text{Let } \alpha'' = \frac{R}{400\,\frac{E+O}{2}\,\sin 1''}.$$

Obtain three values.

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TRANSIT PRACTICE—ANGLE MEASUREMENTS.

Equipment: Transit.

Set up the transit over a designated hub and point at two well-defined points (edge of a cornice seen against the sky or a church spire) which will be also designated. With vernier A at *any* reading (i.e., *not* 0°) set the vertical cross-hair on the *left-hand* point. Read the degrees and minutes of vernier A and the *minutes* of vernier B. Take the mean of the readings of minutes. That, with the degrees of vernier A, constitutes the "mean." Loosen the upper plate, point at the other mark, and clamp again. Again take the mean reading of the verniers. The difference of the means is the horizontal angle. With the upper plate clamped and lower plate loose, turn back to and sight on the left-hand mark and clamp the lower plate. Loosen the upper plate; point at the right-hand mark; clamp the upper plate; take the mean of the vernier readings. The difference between this mean and the previous mean should be practically the same as before. Continue this method until *ten* such values of the angle are obtained. They should not differ more than 1′ of arc. Estimate each vernier reading to half-minutes. Compute the "probable error" of the mean and of a single value of the angle.

FORM OF NOTES.

Vern. A.	Vern. B.	Mean.	Diff.	d	d^2	
20° 16′ 0″	15′ 30″	20° 15′ 45″	—	—	—	Left-hand mark, church steeple, cor. A. & B. Sts.
74° 18′	18′	74° 18′	54° 02′ 15″	6″	36	Right-hand mark, tower finial, cor. M. & N. Sts.
128° 20′ 30″	21′	128° 20′ 45″	54° 01′ 45″	24	576	
182° 22′	22′ 30″	182° 22′ 15″	54° 01′ 30″	39	1521	
236° 24′ 30″	24′	236° 24′ 15″	54° 02′	9	81	$E_1 = .6745\sqrt{\frac{5264}{10-1}} = 16''.3$
etc.	etc.	etc.	etc. ..	etc. ..	etc. ..	$Em = \frac{16.3}{\sqrt{10}} = 5''.1$
			21′ 30″		5261	
		Mean	54° 02′ 09″			

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TRANSIT PRACTICE—TRAVERSING.

Equipment: Transit, transit pole, set of marking-pins.

Set five marking-pins as witnesses near five designated hubs. Set up the transit over one hub; set vernier A at zero; loosen the needle and revolve the whole instrument until the telescope points south, as shown by the needle. Clamp the lower plate; loosen the upper plate and point at the next hub; read vernier A and the needle. Set up the transit at the next hub; plunge the telescope and point at the previous station; test vernier A to see that the plate has not slipped; read the needle; plunge the telescope again to direct position and turn to the third hub and again read vernier A and needle. Take observations similarly at hubs 3, 4, and 5; when at station 5 take a fore-sight to station 1. Finally, reoccupy station 1, sighting back at station 5 for a back-sight; the reading of vernier A for the fore-sight to station 2 should exactly agree with the former reading. A difference of more than a very few minutes of arc indicates gross inaccuracy or a blunder. The object of the needle readings is to guard against blunders. As soon as the vernier and needle readings are recorded, note whether the azimuth and needle reading agree. For example, an azimuth of 217° 42′ signifies a bearing of N 37° 42′ E, and the needle reading should be as near this as it may be read, unless there is local attraction. The degrees on the horizontal plate should be read from the row that is continuous to 360°.

FORM OF NOTES.

Inst. at	Pointing to	Vern A	Needle.			
Sta. 1	South	0°	South			
	△2	274° 03′	S 86° E			
△2	△1	274° 03′	S 85° 50′ E		Tel. rev.	
	△3	192° 16′	N 12° 20′ E			
△3	△2	....	...		Tel. rev.	
	△4	....	....			
etc.						

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TRANSIT PRACTICE—ROD ALIGNMENT; SETTING ALIDADE.

Equipment: Transit, transit-pole, board about two feet long and six or eight inches wide, foot-rule.

1. Send the rodman to a point about 300 feet distant; have him lay the board on the ground where it will be firm, with its length perpendicular to a line to the transit; have him set the rod on the board (near the middle) and measure and record the distance to one end of the board (measuring in inches and *tenths*). The transitman sights at the rod, clamping both plates. The rodman moves the rod away and is again lined in by the transitman. The rodman again measures and records the distance to the end of the board. Obtain 10 such values. Compute the "probable error" of a single sighting and of the mean of all the sightings. Reduce the probable error of the mean to its angular value $\left(\frac{x}{300} = \tan \alpha\right)$.

2. The transitman reads vernier A when the transit points at some one setting of the rod, and between each subsequent setting unclamps and moves slightly the alidade, then resets the alidade at the *same reading* and again lines in the rod as in Part 1. Obtain 10 such values. Compute the probable error and the angular value of the error as before (Part 1).

3. Repeat both of these tests at a distance of about 1000 feet, which may be measured by pacing.

FORM OF NOTES.

Dist.	No. of Rod Setting.	Dist. of Rod from End of Board.	d	d^2		
300	1	12.2	.04	.0016		$E_1 = .6745\sqrt{\frac{1.6240}{10-1}} = .286''$ $= .024'$ $Em = \frac{.286}{\sqrt{10}} = .090'' = .0075'$ $\frac{.0075}{300} = .000025 = \tan 0° 0' 05''$
	2	12.5	.34	.1156		
	3	12.7	.54	.2916		
	etc.	etc.	etc.	etc.		
	....	...	..	...		
	10	11.8	.36	.1296		
		121.6		1.6240		
	Mean	12.16				
300	1	....	....	...	Vern. A 30° 27′	
	2	....	....	...		

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TRANSIT PRACTICE—TESTING ADJUSTMENTS.*

Equipment: Transit, transit-pole, level-rod, 100′ steel-tape, foot-rule.

1. To make the plane of the plate bubbles perpendicular to the vertical axis. Set up the transit and make the plate bubbles parallel to opposite levelling-screws. Bring both bubbles to the centre; revolve exactly 180°. The distance (measured in divisions on the bubble-tube) of the *centre* of the bubble from the *centre* of the scale is *twice* the error. With the levelling-screws throw the transit out of level and begin over again so as to make an absolutely independent redetermination. *Obtain three independent values for the error of this adjustment.*

2. To make the line of sight perpendicular to the horizontal axis of the telescope. Set the transit where a clear sight of about 300 feet each way in opposite directions may be obtained. Point the telescope at some well-defined point (e.g., the corner of a building having a good background). Plunge the telescope and line in the rodman at some point about 300 feet away. Revolve the alidade and point at the first point selected. Again plunge the telescope and line in the rodman for a point beside the one previously set. The distance between these two points is *four* times the error. *Make three tests.*

3. To make the horizontal axis of the telescope perpendicular to the vertical axis of the transit. Set up the transit about 20 feet from the vertical wall of a building. Select a point about as high on the wall as the telescope may be made to point at. Swing the telescope down and have the rodman make a mark on the wall down near the ground. Plunge the telescope, revolve the instrument 180°, and again point at the upper point. Swing the telescope down and have the rodman make another mark beside the first lower mark. A vertical plane through the instrument and the upper mark will pass midway between the two lower marks. Record the distance of the instrument from the wall, the vertical distance (estimated) between the upper and lower points and the distance between the two lower points. *Make three tests.*

4. To make the axis of the telescope bubble parallel to the line of sight. Level the telescope and mark a point on the ground directly under the eyepiece (driving a peg if necessary). Measure the height of the centre of the eyepiece above the point with the level-rod; call the reading a. Establish another point about 300 feet away and at about the same level. Read the level-rod placed on it; call the reading b. Transfer the instrument to the second point and set it up so that the eyepiece is directly over the point. Measure the height of the eye-piece above the point, calling it c, and also read the level-rod held on the first point, calling it d. Then we should have $d - a = c - b$ if the instrument is in adjustment. If not, then $(d - a) - (c - b) = 2m$. $\frac{m}{\text{distance}} = \tan \alpha$. If m is positive the line of collimation points upward. *Make three tests.*

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* See first paragraph of Problem 12, page 16.

5. To make the vernier of the vertical circle read zero when the line of sight is horizontal. This test is only applicable to instruments having fixed vertical circles. As an adjustment it is only applicable to instruments having adjustable verniers. Make the telescope level by means of the level bubble and note the *amount* and *direction* of the "index error." *Make three tests* by turning the telescope out of level between each test.

Best location for these tests. Tests 2 and 4 require an unobstructed, nearly level stretch of 300 feet in one direction, and Test 2 a suitable point about 300 feet in the opposite direction. Test 3 requires a high wall about 20 feet from the instrument, and Tests 1 and 5 may be made anywhere. When an unobstructed line of sufficient length can be found, parallel to a wall and about 20 feet away, a single setting of the instrument will serve for all the tests.

Form of Notes

Test.	1st Trial.	2d Trial.	3d Trial.	Mean.		
1	N .3 div. E 1.2 "	N .5 div. E 1.0 "	N .4 div. E 1.3 "	N .40 div E 1.17 "		Bub. par. to tel. " perp. " "
2	1⅛"	1¼"	1⅝"	1".46	$\frac{1.46}{4} = 0.365$	dist. about 350 ft.
3	$\frac{5}{16}$"	⅜"	¼"	$\frac{5}{16}$"	$\frac{5}{16} + 2 = \frac{5}{32}$	wall 24 ft. from transit; upper and lower points about 40 ft. apart.
4 a	4.26	4.51	4.51		dist. = 364	
b	3.78	4.04	4.02			
c	4.61	4.61	4.47			
d	5.13	5.14	5.03			
m	.02	.03	.035			
$\tan \alpha$	.000 054	.000 081	.000 094			
α	+ 0° 0′ 11″	+ 0° 0′ 16″	+ 0° 0′ 19″	+ 0° 0′ 15″		
5	+ 0° 3′	+ 0° 3½′	+ 0° 2⅛′	+ 0° 03′		

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TRANSIT PRACTICE—STADIA READINGS.

Equipment: Transit, stadia-rod, 5-foot rod (a light rod, graduated in feet and tenths, for obtaining H. I).

Send the rodman to a point about 300 feet away. Note the height of the horizontal axis of the telescope above the ground. Measure the "$f+c$." Point at the rod with the middle cross-wire at a reading on the rod equal to the height of the axis. Read the upper, middle, and lower cross-hairs, also the vertical arc. Note the equality of the upper and lower wire interval. For a check on the distance and as additional practice, move the tangent-screw to the vertical arc *very slightly*, and reread the three cross-hairs. Take ***six*** such readings. [Although by strict theory these wire intervals should differ slightly with any change in the vertical angle, there should be no appreciable variation in them for slight changes, especially if the vertical angle itself is small. For example, with a vertical angle of 10° and a distance of 1000 feet, the vertical angle would have to be changed 10′ in arc to make a difference of 1 foot in the apparent horizontal distance, and 10′ of arc in 1000 feet would mean a movement of 2.9 feet of the wire over the rod.] Compute the true horizontal distance and the difference of elevation.

Repeat these observations at about 600 feet and at about 1000 feet.

FORM OF NOTES.

Approx. Dist.	Wire Readings.	Vertical Angle.	Horizontal Distance.*	Diff. Elev.		
300	6.24 4.80 3.36	– 2° 24′	289	– 12.0′		H. I. = 4.80 $f+c = 1.6$
300	6.27 4.83 3.38					
etc.	etc.					

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TRANSIT PRACTICE—TRAVERSING WITH STADIA.

Equipment: Transit, stadia-rod, set of marking-pins, 5-foot rod.

Make a traverse as in Problem 14, the distances between stations being measured by stadia both while taking fore-sights and back-sights. Unless the transit has a full vertical circle the vertical angle for the back-sight cannot be read with the telescope plunged. It is therefore necessary with most instruments when taking a back-sight to set vernier A at a reading exactly 180° different from the reading for fore-sight, leaving the telescope in direct position. The needle reading should also be 180° different from its reading for fore-sight. Always direct the middle wire to a point on the rod at the same height as H. I. to obtain the vertical angle. The horizontal distance may be most quickly read by raising or lowering the telescope until the lower cross-wire comes on the nearest even footmark and then reading the upper wire. As shown in the previous problem, this involves no appreciable error. Check the horizontal angles by the closure of the last course. Also see whether the algebraic sum of the differences of elevation equals zero. Compute the true horizontal distance to the nearest even foot, the vertical difference of elevation to the nearest even tenth of a foot.

FORM OF NOTES.

Sta.	Vern. A	Needle.	Vert. Ang.	Wire Interval.	Hor. Dist.	Diff Elev.	
Inst. at △1	0°	S					
△2	20° 16′	S 20° 15′ W	− 2° 16′	1.80	181	− 7.1	
Inst. at △2							
B S. △1	200° 16′	N 20° 15′ E	− 2° 15	1.80			
△3	118° 47′	N 61° 10′ W	+ 1° 22′	1.18			
Inst. at △3							
etc.							

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TRANSIT PRACTICE—SAEGMULLER SOLAR ATTACHMENT.

Equipment: Transit with solar attachment, declination tables. The vertical circle of the transit should be fixed and have a vernier reading to half-minutes.

Compute the declination settings for each half-hour for the total period of observations. Set up the instrument over a designated hub. Level up with *extreme care* and note the index error (if any) of the vertical circle. Set vernier A at zero and point at another designated hub or well-defined point. Loosen the upper plate and swing into the meridian by means of an observation on the sun. Read

Form of Notes.

Time.	Decl.	Refr. Corr.	App. Decl.	Azimuth.	Needle.
2:30	+ 10° 27′	+ 0′ 42″	10° 27½′	15° 06′	N 7° 15′ W
36				05	
42				08	
51				05	
3:00	+ 10° 27½′	+ 0′ 48″	10° 28′	06	
etc.				etc.	
				....	
				63	
			Mean	15° 06.3′	

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PLANE-TABLE PRACTICE.

Equipment: Plane table (including alidade, table-level, and compass-box), stadia-rod, steel tape, set of marking-pins. Students must each provide a sheet of drawing paper about 16″ × 24″ (detail paper will answer the purpose), scale, *hard sharp* pencil, and rubber.

Measure a base-line (*AB*) about 300 feet long. Set up the plane table at *A*. Orient the table and draw in the base-line (30 feet to an inch) so that the proposed sketch will come properly on the paper. Draw a magnetic meridian through *A*, using the compass-box. Draw lines toward several points (trees, building corners, etc.), which are visible from both *A* and *B* and, determining their distances by stadia, plot them at once to scale.

Set up the table at *B*; orient by sighting to *A*; check the *orientation with the compass;* check the plotting of the other points by vernier A. Then loosen the upper plate and swing out of the meridian. Swing into the meridian again by means of another observation and again read azimuth by vernier A. Take 10 such observations and compute the probable error of the mean and of a single observation. Observe the azimuth (0°) of the other mark occasionally to see that the lower plate has not slipped. The mean reading of vernier A, if the angles are read in the direction S, E, N, W, will be the azimuth of the line between the hubs. The observations should be taken as rapidly as possible, the change in apparent declination being so small during half an hour that interpolations may be used.

Observe the needle reading when the instrument is in the meridian; it should be the declination of the needle for the time and place.

d	d^2	
0.3	.09	$E_1 = .6745\sqrt{\frac{15.90}{10-1}} = .99' = 59''$ $Em = \frac{.99}{\sqrt{10}} = .31' = 18''.6$
1.3	1.69	
1.7	2.89	
1.3	1.69	
0.3	.09	
etc.	etc.	
....	....	
....	15.90	

(PLANE-TABLE PRACTICE—*continued.*)

sighting to them. Sight to some station point *C*, visible from both *A* and *B*, drawing an indefinite line toward it.

Set up the table at *C*; orient by sighting to *B*; check the orientation with the compass; locate *C* on the drawing by sighting to *A*. Check the plotting of *C* by sighting at some of the other points already located.

NOTES.—In the note-book record date, time of work, number of problem, and personnel of party. The drawing, properly lettered, should be handed in with the note-book. Each student of the party may plot *his own* sheet for each station while the instrument is set there—thus saving time. When another sheet is placed on the table at any station, it simply requires a readjustment of the orientation. The accuracy is not necessarily impaired. *Extreme accuracy in drawing is essential for good results.*

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SEXTANT PRACTICE.

Equipment: Sextant, artificial horizon.

1. Horizontal Angles. Select four well-defined points at least ½ mile away (e.g., chimneys, steeples, etc.). Obtain *four* values for each of the six angles formed at the instrument by the points taken in pairs, as shown below. Loosen the clamp and move the arm slightly between each reading. Unless the points sighted at are very far away, it will be necessary to use considerable care in holding the sextant over a fixed point or an appreciable variation in the angle may be the result.

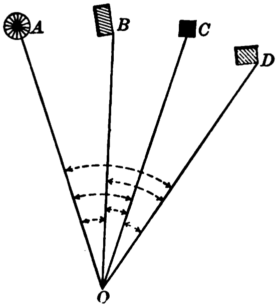
2. Vertical Angles. Set the artificial horizon on a rigid base

Form of Notes.

Angle.	Readings.	Mean.			
AOB	12° 16′ 20″				
	10″				
	30″				
	20″	12° 16′ 20″			
BOC	14° 22′ 40″				
	etc.				
(similarly)					
COD					
AOC					
BOD					
AOD					
Time.	**Double Altitude.**	**Altitude.**			
2 22 35	82° 37′ 10″	41° 18′ 35″			
28 45	etc.	etc.			
31 15	....	....			

and take a position so that the sun will be reflected from the mercury to the instrument. Observe the double altitude of the "upper limb" of the sun by bringing the index image of the sun just tangent to the direct reflection seen through the telescope in the mercury and *apparently* on the *under* side of the mercury image. One half of the angle, minus the refraction correction, minus the semi-diameter of the sun, gives the altitude of the sun. As soon as the images are brought into contact, note the exact time and then read the angle. Obtain 10 values for the altitude of the sun. During the afternoon these values will be constantly decreasing—during the morning they will be increasing. Unfortunately there is no check on this work except a calculation of what the altitudes should be at the given times, which would probably not be obtained closely enough for a very good check.

A; Church steeple, cor. E. and F. Sts.
B; N. E. cor. G. and H. Sts.
C; Tower, City Hall.
D; S. W. cor. M. and N. Sts.



Upper limb of the sun.

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BAROMETRIC LEVELLING

Equipment: Mercurial and aneroid barometers, pocket thermometer. Each student must be provided with a watch, which should be compared before beginning work, and a small sheet of profile-paper (Plate A).

Use of the Mercurial Barometer. The mercurial barometer is to be observed in its fixed position in the office. (*a*) Read the attached thermometer; this should be done first, as the heat of the observer's body will be sufficient to alter the reading in a short time. (*b*) Bring the surface of the mercury in the cistern to the tip of the ivory index. This is most accurately done by raising the mercury (by means of the large screw at the bottom) until the tip dips slightly into the mercury and forms a slight depression; lower the mercury until, as seen by the reflection of light on the surface of the mercury, the depression just disappears. A magnifier will be of assistance in doing this. Tap the barometer *very gently* to destroy the adherence

FORM OF NOTES.

MERCURIAL BAROMETER READINGS.

Time.	Barom.	Att'd Therm.	Red. to 32°.	Red. to Sea-level.	Corr. Reading.
2:00 P.M.	29.782	72.	– .116	+ .063	29.729
2:15	29.776	71.	– .114	+ .063	29.725
etc.					

ANEROID BAROMETER READINGS.

Time.	Place.	Aneroid.	Therm.	Corr. Aner.	Corr. Merc.
2:10	Office	29″.582	74°	——	29″.726
2:25	Roof	.518	62	29.668	.723
2:40	Bridge	.616	65	.761	.720
2:50	Dock	.632	65	.777	.720
3:05	Office	.576	72	——	.722

of the mercury to the glass. (*c*) Raise or lower the slide near the top by means of the screw on the side until a horizontal plane through the lower edge of the slide is just tangent to the upper surface of the *meniscus* at the top of the column. (*d*) Read the vernier; the smallest reading is .002″, but odd thousandths may easily be estimated if necessary. (*e*) To eliminate the effect of temperature on the height of the column, "reduce the readings to 32° F.," by means of the accompanying Table I, interpolating when necessary. For example, assume readings of 29″.632 and 74°; interpolating between 29.5 and 30.0 for 74° we obtain a correction of .121, which is always *subtractive* for the range of values given in the table. 29.632 — .121 = 29.511. (*f*) To eliminate the effect of altitude above sea-level, apply a correction (always *additive*) as given in Table II. The altitude of the barometer above sea-level should be known to the nearest 10 feet. For any one locality, therefore, a single horizontal line of numbers from the table is sufficient. With readings of 29″.511 (as corrected), temperature 74°, and altitude of (say) 60 feet, the correction is +.063, which makes the final value 29″.574. These two corrections render possible a direct comparison of the mercurial and the aneroid readings. These tables are condensed from "Instructions for Voluntary Observers," U. S. Dept. of Agriculture, Weather Bureau. (*g*) Plot the readings immediately on profile-paper (Plate A), using time as abscissæ (one hour per inch) and reduced barometric readings as ordinates (.040″ of mercury per inch).

Elev. of mercurial barometer assumed as 60 feet above sea-level.

Att'd Therm.	Approx. Upper Read.	Approx. Lower Read.	Diff.	Corr. for Temp.	Diff. Elev.
74°					
73	308	253	55	+ 2	+ 57
73	256	218	38	+ 2	− 40
72	256	203	53	+ 2	− 55
72					

Use of the Aneroid. Handle the aneroid with *extreme care,* being especially careful that it is never violently jarred by concussion. Always allow it to lie flat when taking a reading. Tap it with the finger very gently before taking the reading. Ignore the thermometer inside of the aneroid and observe instead the pocket thermometer. If this has been carried in the pocket, allow it to remain in the air (shaded from the sun) long enough to indicate the true temperature of the air. Take readings* (1) beside the mercurial barometer; (2) on the roof of the College Building above the Society rooms; (3) on the floor of the South St. bridge; (4) on the edge of the dock immediately underneath the bridge; (5) finally, another reading beside the mercurial barometer. Correct the aneroid readings on the roof, bridge, and dock by the mean of the discrepancies between the aneroid readings in the office and the reduced mercurial readings. Draw a curve through the ordinates of pressures and scale off the amounts of the ordinates for the times when the aneroid readings were taken on the roof, bridge, and dock. Interpolate for temperature at these times. With these reduced and computed values for the pressures and temperatures, the differences of elevation may be computed from Tables I. and II. of Johnson's Surveying, pp. 132–135, or from any similar tables.

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* The directions are here purely local in their application but were introduced as being suggestive of methods of obtaining a total difference of elevation of 100 feet or over, which is sufficient to illustrate the use of these instruments.

TABLE I.—REDUCTION OF BAROMETER READING TO 32° F.

Temp	Inches.										
	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0
45	—.039	—.039	—.040	—.041	—.042	—.042	—.043	—.044	—.045	—.045	—.046
46	.041	.042	.043	.043	.044	.045	.046	.046	.047	.048	.049
47	.043	.044	.045	.046	.047	.048	.048	.049	.050	.051	.052
48	.046	.047	.047	.048	.049	.050	.051	.052	.053	.053	.054
49	.048	.049	.050	.051	.052	.052	.054	.054	.055	.056	.057
50	.050	.051	.052	.053	.054	.055	.056	.057	.058	.059	.060
51	.053	.054	.055	.056	.057	.058	.059	.060	.061	.062	.063
52	.055	.056	.057	.058	.059	.060	.061	.062	.064	.065	.066
53	.057	.058	.060	.061	.062	.063	.064	.065	.066	.067	.068
54	.060	.061	.062	.063	.064	.065	.067	.068	.069	.070	.071
55	.062	.063	.064	.065	.066	.068	.069	.070	.071	.073	.074
56	.064	.065	.067	.068	.069	.070	.072	.073	.074	.075	.077
57	.067	.068	.069	.070	.072	.073	.075	.076	.077	.078	.080
58	.069	.070	071	.073	.074	.076	.077	.078	.080	.081	.082
59	.072	.073	.074	.075	.077	.078	.080	.081	.083	.084	.085
60	.074	.076	.077	.078	.079	.081	.082	.084	.085	.086	.088
61	.076	.077	.079	.080	.082	.083	.085	.086	.088	.089	.091
62	.079	.080	.082	.083	.085	.086	.088	.089	.091	.092	.094
63	.081	.082	.084	.085	.087	.088	.090	.091	.093	.095	.096
64	.083	.085	.086	.088	.090	.091	.093	.094	.096	.097	.099
65	.086	.087	.089	.090	.092	.093	.095	.097	.099	.100	.102
66	.088	.089	.091	.093	.095	.096	.098	.099	.101	.103	.105
67	.090	.092	.094	.095	.097	.099	.101	.102	.104	.106	.108
68	.093	.094	.096	.098	.100	.101	.103	.105	.107	.108	.110
69	.095	.097	.099	.100	.102	.104	.106	.107	.110	.111	.113
70	.097	.099	.101	.103	.105	.106	.109	.110	.112	.114	.116
71	.100	.101	.103	.105	.107	.109	.111	.113	.115	.117	.119
72	.102	.104	.106	.108	.110	.112	.114	.116	.118	.120	.122
73	.104	.106	.108	.110	112	.114	.116	.118	.120	.122	.124
74	.107	.109	.111	.113	.115	.117	.119	.121	.123	.125	.127
75	.109	.111	.113	.115	.117	.119	.122	.124	.126	.128	.130
76	.111	.113	.116	.118	.120	.122	.124	.126	.128	.130	.133
77	.114	.116	.118	.120	.122	.124	.127	.129	.131	.133	.136
78	.116	.118	.120	.122	.125	.127	.129	.131	.134	.136	.138
79	.118	.120	.123	.125	.127	.129	.132	.134	.137	.139	.141
80	.121	.123	.125	.127	.130	.132	.135	.137	.139	.141	.144
81	.123	.125	.128	.130	.132	.134	.137	.139	.142	.144	.147
82	.125	.128	.130	.132	.135	.137	.140	.142	.145	.147	.149
83	.128	.130	.133	.125	.138	.140	.142	.145	.147	.149	.152
84	.130	.132	.135	.138	.140	.142	.145	.147	.150	.152	.155
85	.132	.134	.137	.140	.143	.145	.148	.150	.153	.155	.158
86	.135	.137	.140	.142	.145	.148	.150	.153	155	.158	.161
87	.137	.139	.142	.144	.148	.150	.153	.155	.158	.161	.163
88	.139	.142	.145	.147	.150	.152	.155	.158	.161	.163	.166
89	.142	.144	.147	.150	.153	.155	.158	.161	.164	.166	.169
90	.144	.147	.150	.153	.155	.158	.161	.164	.166	.169	.172
91	—.146	—.149	—.152	—.155	—.158	—.160	—.163	—.166	—.169	—.172	—.175

TABLE II.—REDUCTION OF BAROMETER READING TO SEA-LEVEL. CORRECTION ADDITIVE.

Height in feet.	Temperature of external air.					Height in feet.	Temperature of external air.				
	40°	50°	60°	70°	80°		40°	50°	60°	70°	80°
10	.011	.011	.011	.011	.010	460	.514	.503	.493	.482	.472
20	.023	.022	.022	.021	.021	470	.525	.514	.503	.493	.482
30	.034	.033	.032	.032	.031	480	.536	.524	.514	.503	.493
40	.045	.044	.043	.042	.041	490	.547	.535	.524	.514	.503
50	.056	.055	.054	.053	.052	500	.558	.546	.535	.524	.513
60	.068	.066	.065	.063	.062	510	.569	.557	.545	.534	.523
70	.078	.077	.076	.074	.072	520	.580	.568	.556	.545	.533
80	.090	.088	.086	.084	.082	530	.591	.578	.566	.555	.544
90	.101	.099	.097	.095	.093	540	.602	.589	.577	.565	.554
100	.112	.110	.108	.105	.103	550	.613	.600	.587	.575	.564
110	.123	.121	.119	.116	.113	560	.624	.611	.598	.586	.574
120	.134	.132	.129	.126	.124	570	.635	.622	.608	.596	.584
130	.146	.143	.140	.137	.134	580	.646	.632	.619	.606	.595
140	.157	.154	.151	.147	.144	590	.657	.643	.629	.617	.605
150	.168	.165	.162	.158	.155	600	.668	.654	.640	.627	.615
160	.179	.176	.172	.168	.165	610	.679	.665	.650	.637	.625
170	.190	.187	.183	.179	.175	620	.690	.675	.661	.648	.635
180	.202	.198	.194	.189	.185	630	.701	.686	.671	.658	.645
190	.213	.209	.204	.200	.196	640	.712	.697	.682	.668	.655
200	.224	.220	.215	.210	.206	650	.723	.708	.692	.679	.666
210	.235	.231	.226	.221	.216	660	.734	.718	.703	.689	.676
220	.246	.242	.236	.231	.227	670	.745	.729	.713	.699	.686
230	.257	253	.247	.242	.237	680	.756	.740	.724	.709	.696
240	.269	.264	.258	.252	.248	690	.767	.750	.734	.720	.706
250	.280	.275	.269	.263	.258	700	.778	.761	.745	.730	.716
260	.291	285	.279	.273	.268	710	.789	.772	.755	.740	.726
270	.302	.296	.290	.284	.278	720	.800	.782	.766	.751	.736
280	.314	.307	.301	.294	.288	730	.811	.793	.776	.761	.746
290	.325	.318	.311	.305	.299	740	.822	.804	.787	.771	.756
300	.336	.329	.322	.315	.309	750	.833	.815	.797	.782	.767
310	.347	.340	.333	.326	.319	760	.843	.825	.808	.792	.777
320	.358	.351	.343	.336	.329	770	.854	.836	.818	.802	.787
330	.369	.362	.354	.347	.340	780	.865	.847	.829	.812	.797
340	.380	.373	.365	.357	.350	790	.876	.857	.839	.823	.807
350	.392	.384	.376	.368	.360	800	.887	.868	.850	.833	.817
360	.403	.394	.386	.378	.370	810	.898	.878	.860	.843	.827
370	.414	.405	.397	.389	.380	820	.909	.889	.871	.854	.837
380	.425	.416	.408	.399	.391	830	.920	.900	.881	.864	.847
390	.436	.427	.418	.410	.401	840	.931	.911	.892	.874	.857
400	.447	.438	.429	.420	.411	850	.942	.922	.902	.885	.867
410	.458	.449	.440	.430	.421	860	.952	.932	.913	.895	.877
420	.469	.460	.450	.441	.431	870	.963	.943	.923	.905	.887
430	.480	.470	.461	.451	.442	880	.974	.954	.934	.915	.897
440	.491	.481	.471	.462	.452	890	.985	.964	.944	.926	.907
450	.503	.492	.482	.472	.462	900	.996	.975	.955	.936	.917

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POLAR PLANIMETER.

Equipment: Planimeter, sheet of drawing-paper about 15″ × 18″, two triangles, scale, drawing-compasses, *hard* pencil. All equipment except the planimeter should be furnished by the student.

Draw on the paper, with *extreme accuracy*, a circle 2″ in diameter, a circle 6″ in diameter, a 2″ square and a 4″ square. The 6″ circle should be nearly in the centre of the sheet, so that when the fixed point is placed inside the circle and the pointer traced around the circumference, the rolling wheel shall not run off the paper. Set the index of the arm of the planimeter at 295.5. With the pointer on some definite point of the perimeter of one of the figures read an initial reading (*not* necessarily zero) on the wheel and vernier. Move the pointer around the perimeter, turning to the right. When the starting-point is again reached, take the final reading. The difference in the readings divided by the known area in square inches gives the reading per square inch. Compute the quotient to three significant figures. Trace each figure similarly *twice*. The readings per square inch on all the figures should agree to a small fraction of one per cent.

Obtain the area of the "zero-circle" by taking the mean of two readings of the six-inch circle with the fixed point *inside* the circle, and then taking the *algebraic difference* of the mean readings (with the fixed point first inside, then outside), which difference, divided by the average reading per square inch, gives the area of the zero-circle in square inches. In taking the reading with the fixed point inside the circle, and the pointer turning as usual to the right, the index wheel will run *backward*, giving a *negative* quantity. Watch the index wheel carefully to note the whole number of revolutions. A simple way is to add, say, 30 to the reading, making it, say, 34.769; watch the wheel run backward through 0, and the readings are then in the twenties. Following it backward similarly until the pointer has again arrived at the starting-point of the perimeter and the reading, say 8.462, can be subtracted from 34.769, thus giving directly the total number of backward revolutions of the rolling wheel. This number is *negative*. The number obtained when the fixed point is outside the circle is *positive*. Therefore their algebraic difference is their numerical sum.

To compute the circumference of the rolling wheel. Use the formula $A = lnc$, in which c = the required circumference, n = the mean record of revolutions per square inch, $l = \left(\frac{295.5}{2}\right)^{mm} = 147.75mm = 5.817$ inches, $A = 1$ square inch.

NOTES.—The drawing, with all results suitably recorded on it, will constitute the report. In the field-book record simply the date, number of problem, etc.

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PANTOGRAPH.

Equipment: Pantograph, sheet of drawing-paper (detail paper will suffice) about 18″ × 24″, two triangles, scale, *hard* pencil. All equipment except the pantograph should be furnished by the student.

Use *extreme care* not to strain the arms or clamps while altering the ratios of the arm lengths. Record in each case by a sketch the arrangement of the fixed point, tracing point and pencil, and also the distances (measured to the nearest .01″) of these points from the pivots.

1. Set the instrument so that it will *magnify* 3.5 diameters and prove the work by making an enlarged copy of a 2″ square, and also of a 2″ circle.

2. Set the instrument so that it will *reduce* 2.5 diameters and prove the work by making a reduced copy of a 5″ square and also of a 5″ circle.

3. Set the instrument to retrace *at the same scale* any given figure and prove by applying it to some irregular figure sketched on the sheet.

NOTES.—The drawing, with all results suitably recorded, will constitute the report. In the field-book record simply date, number of problem, etc.

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RAILROAD SURVEYING—SIMPLE CURVES.

Equipment: Transit, 100-foot steel tape (or link-chain), two transit-poles, set of marking-pins.

Select a point from which may be run two lines making an angle of about 150° and each about 300 feet long. Let this point be the vertex of a curve with an assumed △ (e.g., 28° 46′) and *D* (e.g., 5° 42′).

Compute the tangent distance. Set a pin at the vertex and measure along the direction of one tangent a distance equal to the tangent distance, which will give the P.C. Set up the transit at the P.C. and run in the curve to the P.T. Establish the direction of the forward tangent by a back-sight to the last transit station on the curve. If the vertex is visible from the P.T., sight directly to it and obtain the error (if any) in alignment; measure directly to it and compare the measurement with the computed tangent distance. If the P.T. and vertex are not intervisible, produce the forward tangent backward from the P.T. an amount equal to the tangent

Form of Notes.

Sta.	Alignment.	Vernier.	Tang. Defl.	Calc. Bearing.	Needle.
+02.3	P.T.	14° 23′	28° 46′	N 47° 10′ W	N 47° 15′ W
15	5° 42′ curve left for 28° 46′ Tan. dist. 257.88	14° 15′			
14		11° 24′			
13		8° 32′			
12		5° 42′			
11		5° 51′			
10	P.C.				
				N 18° 24′ W	N 18° 60′ W

distance, and observe the discrepancy between this point and the vertex.

The value of this exercise is increased when the whole curve is not visible from the P.C., thereby rendering necessary one or more transit-stations along the curve. In such cases, and especially when the degree of the curve is an odd quantity, the best plan is to compute all deflections as if the whole curve were visible from the P. C., checking the computation for the last substation by observing its equality to ½ Δ. With the transit at any intermediate station along the curve, instead of following the usual rule and having the verniers at zero when the telescope is tangent to the curve, point at the previous transit station with the verniers reading the *deflection for that station.* Plunge the telescope and point at any forward station with the same deflection as was computed for that station for the transit at P.C. In this way the original list of deflections can be followed and possible error avoided. For example (see below), with the transit at sta. 4, sight back to sta. 2 with a reading of 5° 42′. When the telescope is plunged and the verniers set at 11° 24′ the telescope will evidently be tangent to the curve. An additional deflection of 2° 51′ is necessary to point to sta. 5, and 14° 15′ is the computed deflection for sta. 5. The deflection for any station, visible or not, is the same as from the P.C.

(Read UP the page.)

Error of alignment, 0° 01½′

" " distance, 0′.2

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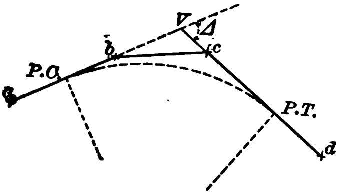
RAILROAD SURVEYING—SIMPLE CURVES, VERTEX INACCESSIBLE.

Equipment: Transit, 100-foot steel tape (or link-chain), two transit-poles, set of marking-pins.

Assume and locate the two tangents by setting two marking-pins for each, so that the central angle will be *about* 30°, and so that the two tangents would intersect within some building or other inaccessible place. Assume D at some value (e.g., 5° 26′) so that the curve will be about 500 to 600 feet long. Suppose a, b, c, and d are the marking-pins. Set up the transit at b; take a back-sight to a and then point to c, thus measuring the angle vbc. Set up at c and similarly obtain the angle bcv. Measure bc, and then compute by trigonometry vb and vc. $vbc + bcv = \Delta$. From Δ and D the tangent distance may be found, and, knowing both this and vb, the P.C. may be located from b. Run in the curve to P.T. Check *alignment* by the direction of cd, and *distance* by measuring from c to P.T.



NOTES.—Similar to those for Prob. 25. Make a sketch (similar to that above) on the right-hand page, recording all the necessary computations.

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RAILROAD SURVEYING—TRANSITION CURVES.

(Searles' Railroad Spiral.)

Equipment: Transit, 100-foot steel tape (or link-chain), two transit-poles, set of marking-pins.

Select a suitable point as the vertex of a curve about 600 feet long, having a central angle of about 30°. Assume definite values for Δ and D and select a suitable spiral. Compute the tangent distance (T_s) for the curve and spiral. Lay off this tangent distance from the vertex; set up the transit at this point and run in the spiral. Set up the transit at the other end of the spiral and verify the setting of all the spiral points by back-sights. Run in the circular curve, locating its middle point (opposite the vertex), to the beginning of the terminal spiral. Set up the transit there and locate that spiral to the P.T. Finally set up at the P.T., verify the points of the terminal spiral, and check the location of the P.T. similarly to Prob. 25. Measure the distance from the middle point of the curve to the vertex and compare the measurement with the computed external distance (E_s).

NOTES.—Same form as for Prob. 25. The chord points of the spiral are recorded as substations with the proper deflection for each in the "vernier" column. The elements of the spiral chosen are recorded in the "alignment" column similarly to those for circular curves.

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RAILROAD SURVEYING—CROSS-SECTIONING.

Equipment: 50-foot tape, hand-level, 5-foot rod, level-rod (or light stadia-rod). ALSO, set of cross-section rods.*

1. With hand-level. Cross-section for 100 feet on each side of a line of stakes, already set by a previous survey. Obtain *distance* and *elevation* for every "break" in the slope, representing distance as the denominator of a fraction and elevation as the numerator. Elevation and distance are always referred to the centre.

2. With cross-section rods. Repeat the cross-sectioning, determining distance and elevation at every 10-foot point as well as at all breaks.

3. Plot one set of cross-sections on cross-section paper (10 lines to

FORM OF NOTES.

Sta.	Surf. Elev.	Grade Elev.	Center cut (+) or fill (−).	Grade.	
etc.	etc.	etc.	etc.		
+60	26.0	36.2	−10.2		
28	26.2	35.8	− 9.6		
27	38.4	25.2	+ 8.2		
26	42.7	34.6	+ 8.1		
25	44.6	34.0	+10.6	+0.6%	

---

* The cross-section rods referred to are a set of three rods, two of them 8 feet long, divided into feet and tenths, and used vertically. The third rod is 10 feet long, divided also into feet and tenths and provided with level-bubbles set

the inch, each way), using the scale of 10 feet to the inch, both for horizontal and vertical scales. The "elevations" (second column of NOTES), which are obtained from a previous levelling, are only used in the plotting. Using the heavy lines on the cross-section paper as even 10-foot elevations, plot first the elevation of "centre," and then, by addition or subtraction, the elevation of each point taken. A line drawn through these points will represent a cross-section of the surface. The intersection of this line by the 5 (10 or 20) foot lines of elevation gives graphically the distance of the 5 (10 or 20) foot contours from the centre. The "grade elevations" and "grade" may be assumed (for the sake of this problem) if they have not been definitely determined, and the "centre cut or fill" computed. Assume the width of road-bed as 20 feet in cut and 14 feet in fill. Assume slope ratio of 1½ horizontal to 1 vertical. Plot the outline of the cut (or embankment) on each cross-section.

4. **Plot** the centre line and contours on drawing-paper.

(Read UP the page.)

Left.	Right.
etc. $\frac{+14.6}{100}$ $\frac{+11.7}{60}$ $\frac{+9.8}{29.0}$ $\frac{+2.6}{13.6}$ $\frac{+2.1}{9.4}$ etc.	etc. $\frac{-3.3}{26.4}$ $\frac{-6.6}{45.0}$ $\frac{-9.7}{62.0}$ $\frac{-11.7}{100}$ etc.

in at each end. They are easily and cheaply made, and very rapid and accurate work may be done with them. On very rough ground, they are probably better than the hand-level and tape. On smooth ground, the reverse is true. Th *method of* use is obvious.

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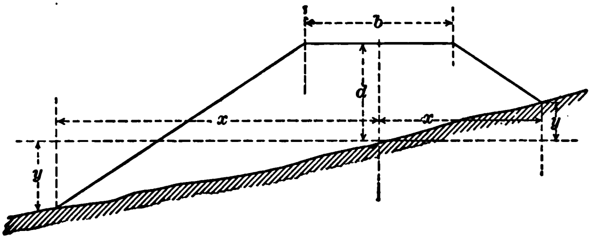
RAILROAD SURVEYING—SETTING SLOPE-STAKES.

Equipment: Level, level-rod (or light stadia-rod), 50-foot tape. Use stakes established by a previous survey, whose elevations are already determined. "Grade elevation" for each stake should also be known. Fill out all the columns on left-hand page of note-book (see below) before beginning field-work. Use the slope ratio 1½ : 1; width of road-bed, 20 feet in cut, 14 feet in fill. Determine the distance and elevation of all "breaks" between the centre and the slope-stakes. Determine the location of the slope-stakes from the formula



$$x = \tfrac{1}{2}b + sd \pm sy.$$

At any station compute first $\frac{1}{2}b + sd$. Then, if on the lower side of a fill (as in figure), estimate by eye how much further than this a

FORM OF NOTES.

Sta.	Surf. Elev.	Grade Elev.	Centre cut (+) or fill (−)	Grade.	
24	92.4	99.8	− 7.4		

point would be so that the added distance would be 1½ times the difference of elevation of the point and the centre. Set up the rod at this total estimated distance. If the difference of elevation (y) satisfies the above formula, x being the horizontal distance from the centre, the point is the required position for the slope-stake. If the formula is not exactly satisfied, a little study will show whether the point should be nearer to or further from the centre and about how much. With practice, two trials will generally be sufficient to determine the point. The upper side of the fill is determined similarly, except that the correction (sy) is negative. For ground level transversely, sy vanishes.

An easy check on the numerical calculation is found by subtracting ½b from the computed distance and noting whether the difference is 1½ times the difference of elevation. For instance, take the result $\frac{3.0}{11.5}$. 11 5 − 7.0 = 4.5, which is 1½ times 3.0; again, 21.4 − 7.0 = 14.4, which is 1½ times 9.6.

(Read UP the page.)

Left.	Right. $b = 14'$ in fill, $20'$ in cut $s = 1\frac{1}{2} : 1$
$\frac{-3.0}{11.5}$ $\frac{-4.7}{3.0}$	$\frac{-8\ 6}{14.0}$ $\frac{-9.6}{21.4}$

PROBABLE ERROR—FORMULÆ AND USE.

[Nothing but a mere statement of working formulæ, with their use, is here given, which the student must take on trust if he has not studied the theory. The proof of these formulæ is taken up in Geodesy.]

1. When a number of separate observations of any kind have been made with equal care, their *arithmetical mean* is the *most probable value* of the quantity observed.

2. The *probable error* is such a quantity that it would be an even wager that it is greater or that it is less than the real error. For example, if the measurement of a base-line is given as 622.456 ± 0.096, it means that the arithmetical mean of several equally good measurements was 622.456; that the probable error (computed as below) is 0.096; that according to the mathematical laws of the theory of probability there is *as much chance* that the real error of 622.456 is *less* than 0.096 as that it is *more*.

3. Let n = the number of observations;
d = the difference between any one observation and the arithmetical mean (or the "weighted mean");
E_1 = the probable error of a single observation;
E_m = the probable error of the mean;
c = 0.6745, a constant determined by computation according to the theory;
Σ = a symbol signifying that a summation should be made of all the quantities represented by the following letter or letters.

Then

$$E_1 = c\sqrt{\frac{\Sigma d^2}{n-1}}$$

$$E_m = \frac{E_1}{\sqrt{n}} = c\sqrt{\frac{\Sigma d^2}{n(n-1)}}.$$

For example:

Angle.	d	d^2
66° 54′ 12″.5	+1.1	1.21
13 .5	+0.1	01
11 .3	+2.3	5.29
16 .5	−2.9	8.41
12 .8	+1.3	1.69
15 .5	−1.9	3.61
Mean, 66° 54′ 13″.6		20.22

$$E_1 = .6745\sqrt{\frac{20.22}{6-1}} = \pm 1''.33.$$

$$E_m = .6745\sqrt{\frac{20.22}{6(6-1)}} = \pm 0''.54.$$

Angle = 66° 54′ 13″.6 ± 0″.54.

4. Weighted Observations. When observations have not been made with equal care or are not equally reliable they are "weighted" according to their reliability. If M represents any observation and w its weight, then the "weighted mean" $= \dfrac{\Sigma(wM)}{\Sigma(w)}$. Subtract each observation from the weighted mean to obtain d. Then, with the other symbols as before,

$$E_1 = c\sqrt{\frac{\Sigma(wd^2)}{n-1}} = \left\{ \begin{array}{l}\text{the probable error of an observation of}\\ \text{weight unity;}\end{array}\right.$$

$$E_m = c\sqrt{\frac{\Sigma(wd^2)}{(\Sigma w)(n-1)}} = \text{the probable error of the weighted mean.}$$

For example:

Angle.	w	d	d^2	wd^2
116° 43′ 48″.81	5	+0.83	0.69	3.45
48 .76	4	+0.88	0.77	3.08
49 .53	5	+0.11	0.01	0.05
51 .56	3	−1.92	3.69	11.07
50 .38	2	−0.74	0.55	1.10
49 .84	5	−0.20	0.04	0.20
116° 43′ 49″.64				18.95

$$E_1 = 0.6745\sqrt{\frac{18.95}{6-1}} = 1''.32.$$

$$Em = 0.6745\sqrt{\frac{18.95}{24(6-1)}} = 0''.27.$$

Angle = 116° 43′ 49″.64 ± 0″.27.

NOTES ON THE MANAGEMENT OF A STUDENTS' TOPOGRAPHICAL-HYDROGRAPHICAL SURVEY.

The following directions were originally written for the purpose of supplementing the general treatment of the subject, as given in a text-book on surveying, by specific instructions applied to the locality of the survey—a section of Fairmount Park, including a stretch of the Schuylkill River and a considerable area along the banks. They have been incorporated, with some revision, into this book because it is believed that they are sufficiently applicable to any similar survey to warrant their publication.

The triangulation methods are those for tertiary work, and the directions for "precise" base-line work, latitude and longitude, were inserted as exercises for the upper classmen, and not because they are essential to the proper conduct of the survey.

A. Reconnoissance; Location of Stations.

1. Two parties are necessary—one on each side of the river. Each party should be supplied with stakes, a heavy hatchet or axe, a pocket sextant (or prismatic compass), three transit-rods with flags tacked on, and a light crowbar.

2. In general four lines will run from each station—two to stations above and below on the same shore and two to stations on the opposite shore. The distance between stations along one shore should be, when possible, a little more than the width of the river so as to obtain nearly equilateral triangles.

3. The *forward* rodman on each side is controlled by the party on the *other* side. When the forward rodman reaches a suitable location that gives satisfactory angles (as near 60° as possible) to *both* parties he remains there until dismissed by *both* parties. The rear flagman on each side occupies the station last occupied by the main party.

4. The angles between stations should be measured with a pocket sextant to the nearest degree. These should be plotted at night so that any necessary modifications can be promptly made, and then the stations can be properly numbered as a basis for future field orders.

5. All triangulation stations should be marked by stakes 2″ × 2″ × 18″, centred with tacks, driven to within 4″ of the ground, using a crowbar to make a hole if necessary. The stakes for the ends of the base-line should be longer; they should project at least 12″.

B. BASE-LINE. Precise Method; accuracy 1 : 1 000 000.

1. The site for the base-line should be nearly level, and on as uniform a surface as possible. The roadways on the river-banks generally afford the best sites.

2. A hub should be set every 300 feet, measuring from one end; also, a hub should be placed within 10 feet of the other end and at an even 10-foot distance from the last 300-foot hub placed. The hubs should be long enough to project 12″. At every 50 feet between the hubs 3-foot stakes should be driven so that the base-line would pass about ½″ from the face of the stake. Screw-eyes with 3″ hooks should be screwed into the faces of these stakes so that the bottom of each hook is on the grade-line between the tops of the adjacent hubs. The hooks should have the points bent upward, and the screws should be so set that the hooks will point outward and swing freely in both directions. Strips of zinc should be nailed to the tops of the hubs. While obtaining the grade-line between hubs, the differences of elevation of all adjacent hubs should be noted.

3. The tension-frames* should be used with a tension of 16 lbs. The rear end of the tape is placed exactly on the station mark, the forward end screwed up until the tension of 16 lbs. is obtained, every hook support critically examined to see that the tape rests with perfect freedom in the hooks, and then a fine mark is scratched in the zinc strip on the hub with a fine steel point. Then the tape is moved ahead. While measuring, two thermometers should be tied to the tape near the 100-ft. and 200-ft. points (marked 90 and 190 on the U. Pa. 300-foot tape), and the readings taken to the nearest tenth of a degree at every measurement. These thermometers should be carefully standardized and their exact errors known. The last sub-distance (less than 10 feet) is measured with a fine 10-foot steel tape, graduated to .01′ and estimated to .001′.

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* The tension-frames referred to were designed by the author. They provide for accurate adjustment of the tape over the hubs and an extremely accurate measurement of the tension—by a scale-beam and *not* by a spring. The frames are of tubing, with pointed ends, and are easily adjustable, tripod fashion, over the hubs.

4. Measurements should not be made, unless for mere practice, while the sun is shining on the tape. A calm, cloudy day should be chosen, and even better results are obtained during a drizzling rain. In default of cloudy days, measurements should be taken immediately after sundown or before sunrise. For the best results the earth and atmosphere should have the same temperature. This probably occurs during the evening, but then lanterns must be used, endangering the accuracy.

C. BASE-LINE. Ordinary Method; probable accuracy, 1 : 50000.

1. Measure the base-line *three* times with an ordinary 100-foot steel tape, using fine brass plumb-bobs to plumb down the tape ends to the tops of stakes set every 100 feet. The mean temperature of the air should be noted with a pocket thermometer, and corrections made accordingly. Care should be used to have a uniform tension of as near 16 lbs. as possible. A spring-balance should be used for this.

2. The mean of these measurements may be used as the final value for the triangulation should anything prevent the "precise" measurement (B).

3. A check-base should be measured at or near the other end of the system of triangulation.

D. AZIMUTH.

1. Azimuth may be determined by a set of observations with a solar attachment. At least twenty observations should be obtained having an extreme range not greater than 3′ of arc (see Prob. 19). The observations should be taken at a triangulation station, and each observation consists in finding the angle between the meridian, as determined by that observation, and a line to another triangulation station.

2. Azimuth may also be determined by night observations on Polaris (or 51 Cephei) at elongation, or at *any* time provided that true *local time is accurately known*. (See Johnson's Surveying, § 381 a;

or Manual of Instructions, issued by the Commissioner of the General Land Office in 1890.)

3. A valuable check on the work may be obtained by taking azimuth at stations near each end of the triangulation, making corrections, if necessary, for the convergence of meridians.

4. True latitude (as close as the reading limit of the vertical arc of the transit) should be known. If it is not obtainable from an accurate map of the section of the country, it must be observed as provided below.

E. LATITUDE.

1. Observations for latitude may be made by observing the culmination of Polaris (or 51 Cephei) at the same time that the elongation of 51 Cephei (or Polaris) is observed for azimuth.

2. Latitude may also be obtained by transit (or sextant) observations on the sun at culmination, making allowance for the declination and refraction. (See Prob. 21, part 2.)

F. LONGITUDE.

1. Observations for longitude may be made by observing selected pairs of stars. (See Johnson's Surveying, §§ 382–392.) The true meridian should be accurately known for this work; a portable chronometer, with a known rate and a known error with reference to standard time, is also essential; the approximate longitude must also be known.

G. TRIANGULATION.

1. Sightings may be taken (1) at a transit-rod, held by a rodman, pointing as near the bottom of the rod as possible, noting by the vertical cross-hair the verticality of the rod, or (2) at a transit that may be occupying the station, pointing at the plumb-bob or at the vertical spindle underneath the plates. When it is evident that a station occupied by a transit party is being sighted at by another party, care must be taken to facilitate their work by not obstructing the line of view and always giving them a good mark to sight at. If a transit which is being sighted at is removed from the station, it should be promptly replaced by a rod.

2. *Angles* should be measured by the method outlined in Prob

13. Measure by repetition until six *consecutive* values are obtained having an extreme range not exceeding 2′ of arc. Compute the mean value.

3. All triangles must "close" with an error not exceeding 1′ of arc.

4. As fast as the angles of the triangles are *satisfactorily* measured, the sides should be computed from the measured base, the true azimuth of each triangulation line determined, and the whole triangulation plotted.

H. Levelling.

1. A line of levels should be run along each bank of the river, noting the elevation of each triangulation station and also of the water surface near each station.

2. A tide-gauge should be set up in a suitable place, the elevation of its zero determined, and readings to the nearest tenth of a foot taken as often as proves necessary, while the line of levels is run and while stadia topography is being taken.

I. Soundings.

1. Soundings to a depth of 18 to 20 feet may be made with a sounding-pole. A sounding-line with weight will be needed for a large part of the soundings above the Girard Ave. Bridge (max. depth about 36 feet).

2. Lines of soundings should be run nearly perpendicular to the course of the river and about 300 to 500 feet apart; the individual soundings about 50 feet apart.

3. The soundings should be located by two transits on shore pointing at each other and at the boat. As a check, a sextant in the boat points at the two transits. Each transit is set at 0° on the other transit, the lower plate always clamped, the upper plate free, the movement of the boat constantly followed with the telescope.

4. At the instant of taking a sounding, a signal will be given from the boat—a waving flag or a whistle. The shore parties will note *first* the *time* of the signal, and *second* the angle to the boat. Since it will not increase the accuracy of the plotting, the angles need not be read closer than the nearest 10′ or 15′, and so it will be *easier and better to take the* reading directly from the index, not

even reading the vernier. The transitmen should point at the sounding-pole as nearly as possible.

5. The shore parties and the boat party must be supplied with watches, previously compared to a close fraction of a minute. It will save trouble in identifying the shore and boat records if the soundings (and signals) are made always at an even minute of time, and never oftener than once per minute. An occasional signal of *two* whistles (marked as such in all the note-books) will also aid in identifying the soundings, especially when mistakes have been made.

6. The shore parties should be located at triangulation stations when they are suitable. Otherwise, points which are especially desirable for this purpose may be selected and their locations accurately determined from the triangulation stations.

7. The following form of notes should be used for the note-book in the sounding-boat:

Line.	Time.	Sextant Angle.	Angle.	Depth.	Bottom.
4—D_2	2:34	*E*—boat—*D*	62° 20′	15.7	Sandy
	2:36		68° 40′	18.2	"

The right hand page should record the personnel of the party and any other desired information. D_2 means the second point on the shore below Sta. *D* toward (or away from) which a line of soundings has been run. The note-books of the shore parties should observe the following form:

Inst. at	Line.	Time.	hore Angle	Angle	
Δ *D*	4—D_2	2:34	boat—*D*—*E*	45° 10′	
		2.36		42° 30′	

8. During the evening following the sounding work, the soundings in the sounding-book should be numbered consecutively and the corresponding shore angles numbered with the same numbers, the correspondence being determined by the identity of time, verified by double signals, etc. These checks of double signals, etc., *are often* proved valuable.

J. TOPOGRAPHY.

1. Topography is taken by stadia lines, which must always begin and end on triangulation stations or other points equally well determined. Beginning at some station, the telescope should be pointed at some other known station, with the plates set at the known azimuth of that line.

2. Distance and vertical angle are read both for fore-sight and back-sight between stadia stations. Side shots are taken to all desired points within a radius of 500 to 600 feet.

3. One line should be run near enough to the shore line to take in all the configurations of the shore and also a belt of land from 200 to 600 feet wide—varying with the interference of trees and bluffs. The vertical angles to shore points should be noted with especial care, as it furnishes a valuable check on the levels.

4. The course of the other meander lines should depend largely on the topography. In general, they should follow roads, etc., so as to pass as near as possible to the important points that must be observed, and yet must pass near enough to the other lines that no feature of topography will be omitted.

5. If the transits contain fixed stadia wires, a careful test of them should be made at the beginning of the season's work, and if the interval does not correspond with the graduation of the rod, a reduction coefficient should be computed and applied to each reading. If the wires are adjustable, tests should be made frequently, even daily, considering how simple it is. Measure off a base-line 600 feet long on level ground near headquarters. Each morning, before beginning stadia work, set up the transit at a distance "$f + c$" behind one end of the base-line, and read the rod held at the other end. An error of more than 1 : 600 should be immediately adjusted, after consultation with an instructor. If the first "set-up" of the transit is to be at a triangulation station, it may be more convenient to begin there at once and point to another station whose distance is known, and take the reading, making due allowance for the "$f + c$."

6. Further instructions on this subject, together with a form of notes, may be found in the instructions for a preliminary survey (railroad work) on pp. 58–61.

K. COMPUTATIONS; PLOTTING.

1. The closure of triangles within the required limits must be determined as soon as possible, and the angles remeasured if necessary.

2. The azimuth and length of all triangulation lines must be computed as soon as sufficient data are obtained.

3. To check topographic work, the co-ordinates of all triangulation stations from some chosen meridian and parallel should be computed before topographic work commences.

4. The latitudes and departures of the lines between stations of the topographic work should be computed and checked with the previously computed co-ordinates of the triangulation stations to which the stadia lines run.

5. For such lines as are run on this survey—probably less than ½ mile between such stations as are used to check on—the errors should be within 10 feet horizontal distance and 1 foot in vertical height.* Greater errors than these call for a thorough revision of notes to discover a possible error, and perhaps a resurvey.

6. The triangulation should be plotted to a scale of 200 feet to the inch as soon as the computations are complete.

7. All soundings should be plotted during the progress of the survey, or at least sufficient of them to show the general accuracy and reliability of the notes.

8. All topographical notes should be plotted during the survey (at least in pencil)—plotting first the transit stations until the line checks with sufficient accuracy on some known station and then plotting the side shots, locating all drives, walks, buildings, rail roads, bridges, etc.

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* These errors are very large considering what accuracy is possible with the stadia, but it is doubtful if much closer work than this can be expected of inexperienced students.

NOTES ON THE MANAGEMENT OF A STUDENTS' RAILROAD SURVEY.

It should be remembered that students' surveys are made primarily to teach the students. Therefore, although it is desirable to simulate regular professional practice as far as possible, matters of speed and economy should sometimes be subordinated, so that the students may receive the maximum benefit.

RECONNOISSANCE.

A reconnoissance survey is a very hasty examination of a wide belt of country to determine which routes will best justify further and closer instrumental examination. In practice they vary from a trip made on horseback, depending principally on "judgment" and "an eye for country," to an instrumental survey differing but little in character from a preliminary survey. The prime object is to determine with the greatest rapidity and least expense the salient features which will condemn one proposed route and commend another, or which will narrow down the choice to two or three lines that are so evenly balanced that a closer survey of each is necessary to decide between them. In places where the topographical maps of the U. S. Geological Survey (or other similar maps) are available, no reconnoissance (at least so far as the *physical* characteristics of the country are concerned) is necessary; a general route may be chosen from the map and the preliminary survey at once made. In all civilized countries some sort of a map can generally be found, although coarse and inaccurate. The method here outlined presupposes the availability of a map which will give the relative *horizontal* positions of prominent features of the country, such as cross-roads, streams, etc., with such a degree of accuracy as county maps, as ordinarily made, are found to have. In the absence of such a map a better method of obtaining distances should be adopted.

The instrumental equipment consists of a mercurial barometer, an aneroid, a pocket thermometer, a pocket compass, and a hand-level. The mercurial barometer should be maintained at headquarters and read every half-hour during the periods when the aneroid is being read in the field. The altitude above sea-level of each location for headquarters should be obtained if possible by a comparisome with some known altitude, points on another railroad, a geodetic survey station, etc. If nothing of the kind is available, extraordinary care should be used in obtaining the difference of elevation of the different locations for headquarters.

Distances may be estimated, paced (aided perhaps by a pedometer), or measured when convenient with an odometer. Azimuth may be measured with a pocket compass, and altitudes with the aneroid.

The survey line should start from some known place on the map (generally some town), and should pass through all points which will probably be determining points on the road. In the course of a few miles it will probably pass within range of some easily identified point—a road crossing, bridge, hamlet, etc. "Side shots" should be taken to all such points and to any points whose position might have some bearing on the proper location of the road. Sketches should be made on the right-hand pages of the note-book on a scale of 400 feet to the inch, sketching not only the topographical features, but also the *form* of the contours. During the evenings following each day's work in reconnoissance the aneroid observations should be reduced (by comparison with the plotted mercurial readings for the day) and entered in the note-book. (See Prob. 22.) Then the line should be plotted on the map of the country that has been obtained for a basis, modifying the location of the points by making the plotting of well-defined points agree with the (probably) more correct map used as a basis and drawing in contours as well as the data will permit, utilizing the aneroid elevations. From this rough map may be decided what line (or lines) will justify a further and closer examination by means of the "preliminary survey."

FORM OF NOTES. RECONNOISSANCE SURVEY.

Observer at	Bearing.	Distance.	Aneroid.	Reduced Elevation.	Sighting at
	S 70° W	500′			Hill about 90′ high.
	N 5° E	600′			Road corner.
			29″ 922 64°	....	Creek under bridge.
	N 5° E	50′			bridge.
	N 25° W	950′			△ 23
△ 22			29″.860 66°	....	

PRELIMINARY SURVEY.

The party should consist of a transitman, recorder, two rodmen with stadia-rods, stakeman, leveller, and level-rod man, and a topographer.*

Azimuth at the first station should be determined as accurately as possible by a needle-reading, setting vernier A at zero, with the needle pointing south. A splendid check on azimuth may be obtained by using a solar attachment at the beginning and end of the survey, and also at intermediate points at intervals of a few miles, making due allowance for the "convergence of meridians." The extra time required for these check observations is insignificant. Carry the traverse throughout the survey by the same method as in Prob. 18.

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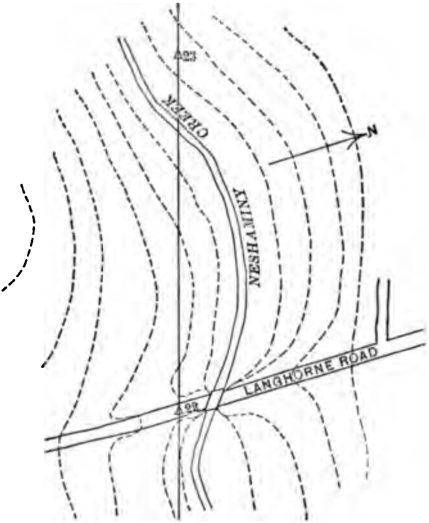
*See note on page 61.

Read UP the page.



Particular care should be taken in observing the distances between stations. Not only should the distance be read both during fore-sight and back-sight observations, but if the sighting is not very clear for any reason repeated sightings should be taken as suggested in Prob. 17. If the back-sight does not agree with the previous fore-sight, the error should be located until there is no doubt of the true distance.

Take " side shots " to all fence corners, road bends, river bends, buildings, salient points of ground surface, and any other points necessary to obtain a topographical map with 5-foot contours, throughout the belt of country traversed by the survey. The width of country necessary to be surveyed varies with the topography. It should include a considerable width each side of any probable location of the road in that belt. Even when topographical features determine the location to within a few feet, the topography should be taken for 200 feet on *each side*. From this minimum width it should be increased up to 1000 feet each side as the uncertainty of possible location increases. Much time and work can be saved by limiting the observations that are taken only for contours to points that are the salient points—in the bed of a stream or dry gully, the comb of a ridge, the edge of a bluff, etc.

The elevations of all stations should be determined with a wye-level to the nearest tenth of a foot. Benches and turning points should be read to the nearest hundredth. A bench-mark should be established every half-mile.

The topographer should plot his work on section-paper at a scale of 200 feet to the inch, plotting first each station point and then the position of the more prominent stadia points, using azimuths and unreduced stadia readings as aids in plotting distances; using the level notes of elevation of stations to determine where the 5-foot contours cross the traverse line, observing (with hand-level) the course of each contour throughout the area included by the survey. A sketch-board, about 18″ square, mounted on a very light tripod, is very useful for this work. The board should be oriented at each station. A ruler may be used as an alidade. as in plane-table work, and a very reliable and valuable sketch may be rapidly made. Of course this sketch is not expected to take the place of the office map, but it will render the office plotting very easy and certain.

FORM OF NOTES. PRELIMINARY SURVEY.

	Vern. A.	Needle.	Wire Int.	Vert. Angle.	Red. Dist.	Diff. Elev.	Elevation.
F. S —Δ 27	62° 47	S62°45 W	5.63	+0° 52′	564	+ 8.5	172.76
	....	——	....	....	......	....	....
	etc	——	etc.	etc.	etc.	etc.	etc.
	322° 14′	——	8.47	+3° 21′	844	+49.6	2.14
B. S.—Δ 25	265° 18′	N85° 15′E	4.22	– 0° 16′	423	– 2.0	——
Inst. at Δ26							164.28

During the evening following each day's work in the preliminary survey the "reduced distances," "differences of elevation," and "elevations" are to be computed from the notes and entered in the note-book. Then the work is to be plotted on detail paper to a scale of 200 feet to the inch. The "paper location" should then be studied and drawn on the preliminary map. From the intersection of this line with the contours an approximate profile may be drawn which will be valuable in giving an idea of the amount of cut and fill, and will be especially valuable in comparison with one or more profiles similarly obtained from other proposed locations.

LOCATION SURVEY.

The location party may consist of a transitman, a recorder; two tapemen, two rodmen, a stakeman, two cross-section men, a leveller, and a level-rod man. When short of men the transitman may keep notes and one rodman may be dispensed with.*

Stakes should be located at every station (at least) on tangents, every 50 feet on curves up to 6°, every 25 feet on sharper curves; also at all abrupt changes in the profile (both to increase accuracy in chaining and to locate points for the leveller). Stakes should be marked on the ***rear*** side, with the number of the station and its plus-distance, if any. Transit hubs should be driven flush with the ground, the exact centre marked with a tack, and should have a witness-stake set three feet to the left, with the distance and P.C. or P.T., etc., marked on it, the marking facing the hub.

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* To render these student surveys as free from objection (and expenses for damages) as possible, cutting and clearing is avoided wherever possible. With a superabundance of men, branches can be held back and cutting often avoided. Therefore no reference has been made to axemen, either in this or in the preliminary survey. The force of men is ample to supply an axeman for all cutting that is indispensable. The necessity for clearing is allowed considerable weight in selecting the locality for these surveys.

(Read UP the page.)

(level, 172.73.)

to fence cor. near barn.

The leveller should observe the elevation of all stations and substations, and should even interpolate points with a tape and observe their elevations when it will add to the accuracy of the profile. The B M.'s of the preliminary survey should be used and checked as long as they are within range of the location line. New B.M.'s may be interpolated when necessary. The rod should be read to the nearest tenth on stations and to the nearest hundredth on turning-points and bench-marks. The profile of each day's work should be promptly plotted at night on profile-paper, Plate A, using horizontal scale 200 feet to the inch, vertical scale 20 feet to the inch.

FORM OF NOTES. LOCATION SURVEY.

Sta.	Alignment.	Vernier.	Tang. Defl	Calc. Bearing.	Needle.
▵ +47	P.T.	6° 10′	12° 20′	N 1° 24′ E	N 18° 0′ F
52	4° curve right for 12° 20′ Tang. dist. = 154.80	5° 13½′			
51		3° 13½′			
50		1° 13′			
▵ +39	P.C.				
49					
48					
▵ +50	P.T.	7° 20′	14° 40′	N 10° 56′ W	N 11° 0′ W
47	2° 40′ curve left for 14° 40′ Tang. dist. = 276.54	6° 40′			
		6° 00′			
		5° 20′			
▲ +50		4° 00′			
46		3° 20′			
45		2° 40′			
		1° 20′			
▵ +50					
44					
43					
▵ 42	P.C.			N 3° 44′ E	N 8° 40′ E

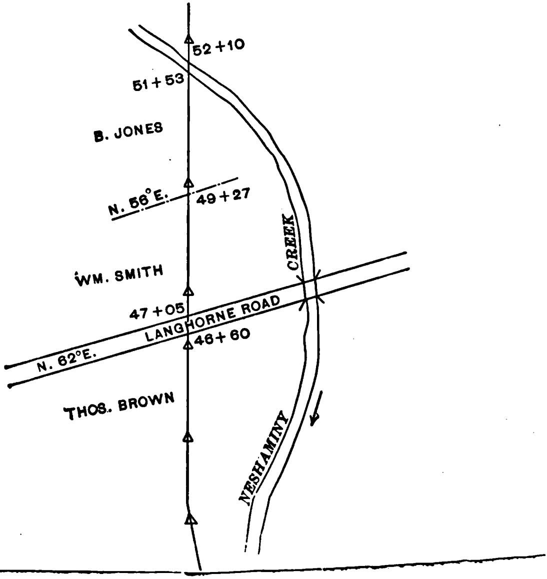
The transitman should " tie on " to the stakes of the preliminary survey, whenever possible, not only as a check on the work, but also to observe and correct any departure from the line as laid out on account of inaccuracies in the paper location.

The cross-section men should work by the methods and with the form of notes elaborated in Prob. 28. The width of the cross-sections may be varied according to the amount of cut or fill that would evidently be required. They should be made about 50 feet wider than the probable width of top of cut or base of fill. They should be plotted at night on cross-section paper.

The location map should be plotted at night to a scale of 200 feet to the inch, drawing in 5-foot contours from the cross-section notes and borrowing other topographical details not observed during the location survey from the preliminary survey map.

The form of notes for the location survey should be as on pp. 62, 63:

(Read up the page.)



When the location profile has been completed for a sufficient distance so that the "grade-line" may be laid out, it should be drawn in, and then a list of "surface elevations" and "grade elevations" for each station and substation should be entered in the slope-stakes book; also (as near as possible) the position of grade points for centre line and edges of road bed. Then, knowing the "centre cut (or fill)," the positions of the slope-stakes, breaks, etc., are to be found and notes entered as described in Prob. 29. When men are plenty the party may consist of a leveller, computer and recorder, and two tapemen, one carrying the rod.

To measure the volume of the terminal pyramid when emerging from a cut, take a cross-section at point where the side of the road-bed that first emerges from the cut actually comes out. Measure the perpendicular distance from this cross-section to the point where the other side of the road-bed emerges. The area of the cross-section times one third of this distance gives the volume. The volume of the initial pyramid of fill is similarly obtained. If the width of road-bed in cut and fill is the same, the altitudes of the pyramids are the same, and the apex of one lies in the base of the other; otherwise they are separated by a small distance. If the line of intersection of the road-bed and the surface is nearly perpendicular to the line of road, no appreciable error is involved in treating the terminal volumes as wedges, having as bases the nearest convenient cross-sections, and as altitudes the distances measured along the road-bed from these cross-sections to the intersection of grade-line with the surface.

To find grade points, set the target of the level-rod at a reading equal to the difference between the height of instrument and the elevation of grade-line at the point where the grade point is supposed to be, as determined by the profile. The uncertainty as to grade elevation, on account of the uncertainty as to the exact grade point, is usually too small to be considered. Have the rodman move along the centre line (or the side lines of the road-bed), and the point where the target is level with the instrument is the grade point.